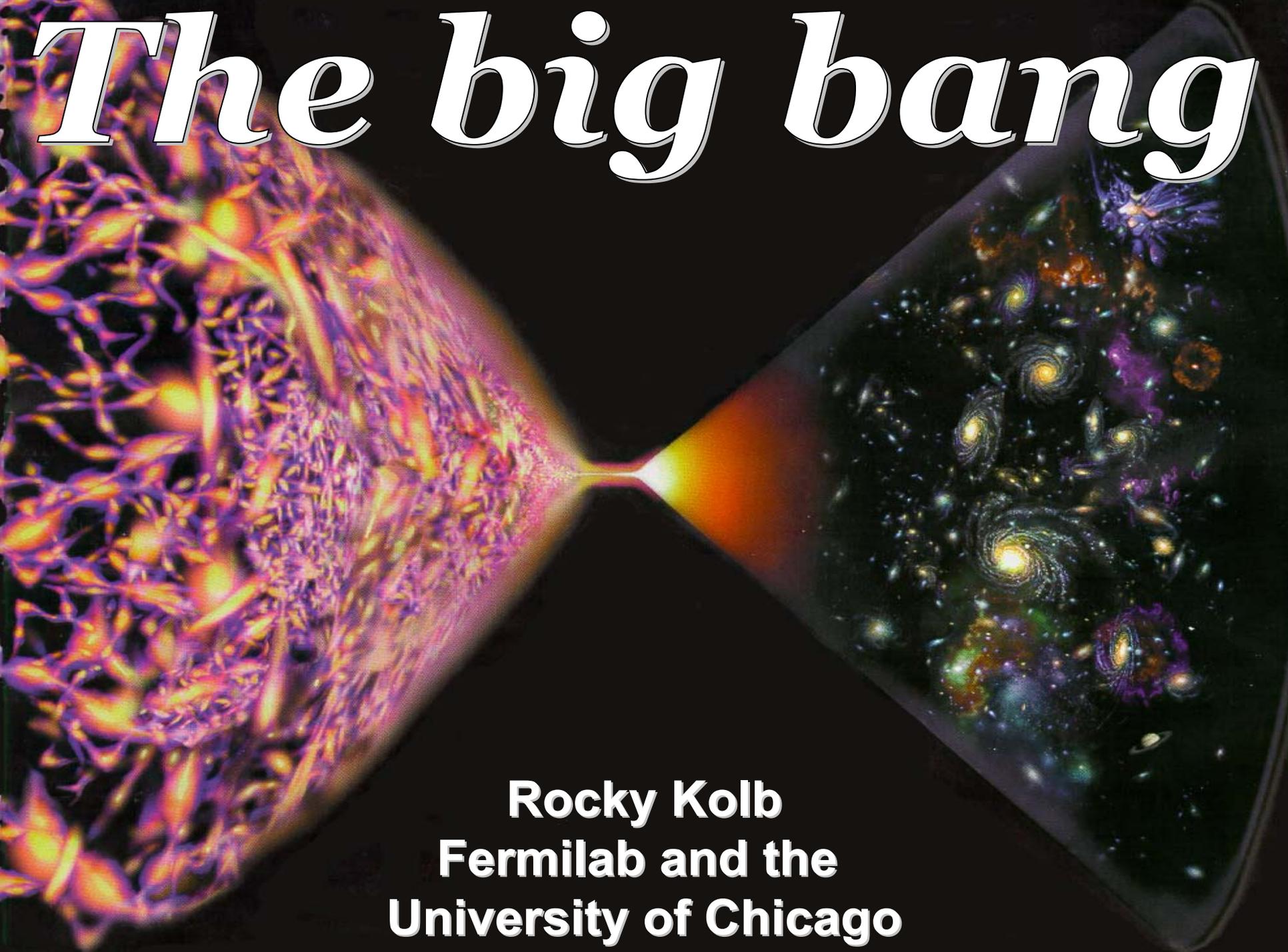
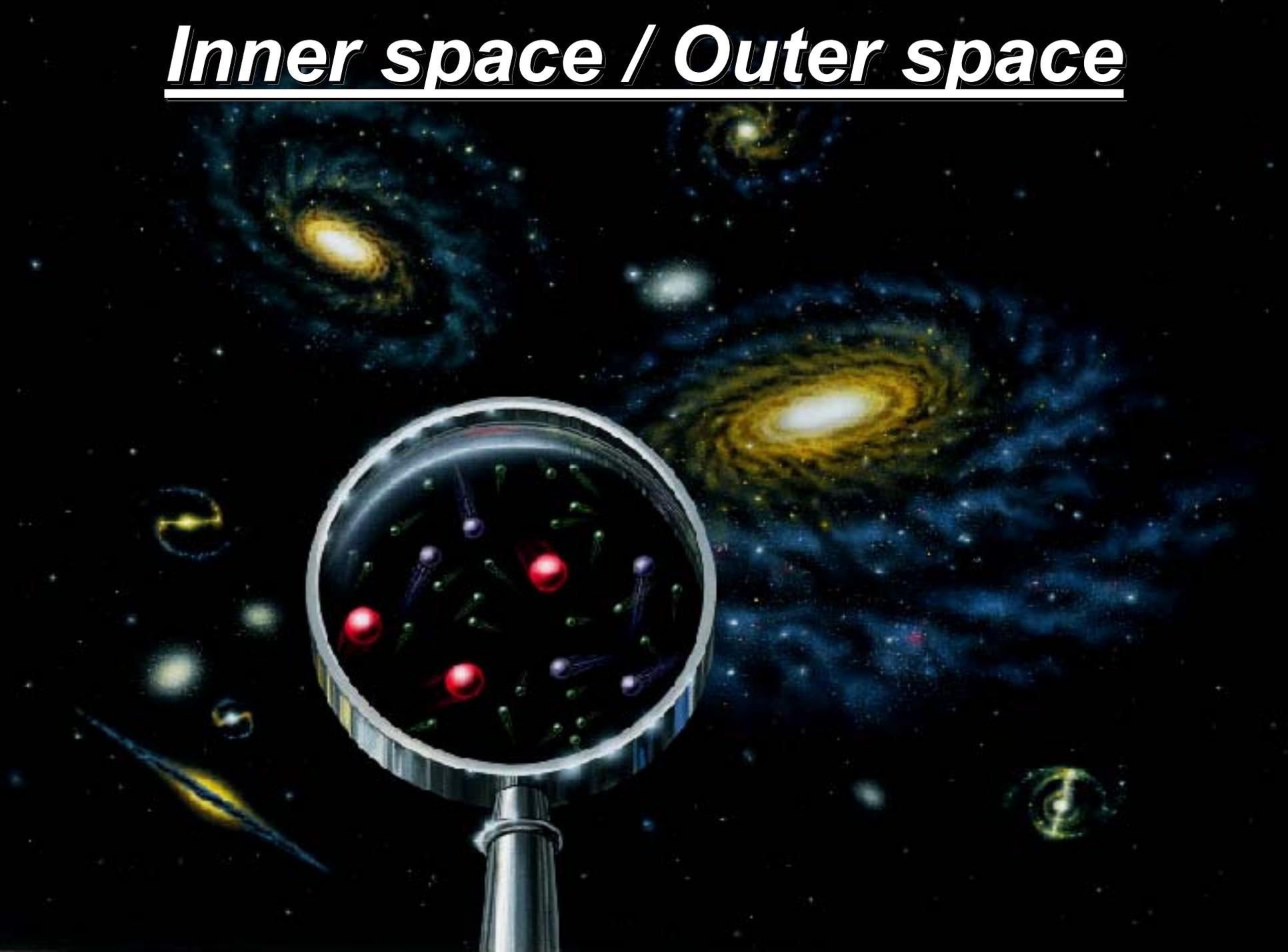


The big bang



**Rocky Kolb
Fermilab and the
University of Chicago**

Inner space / Outer space

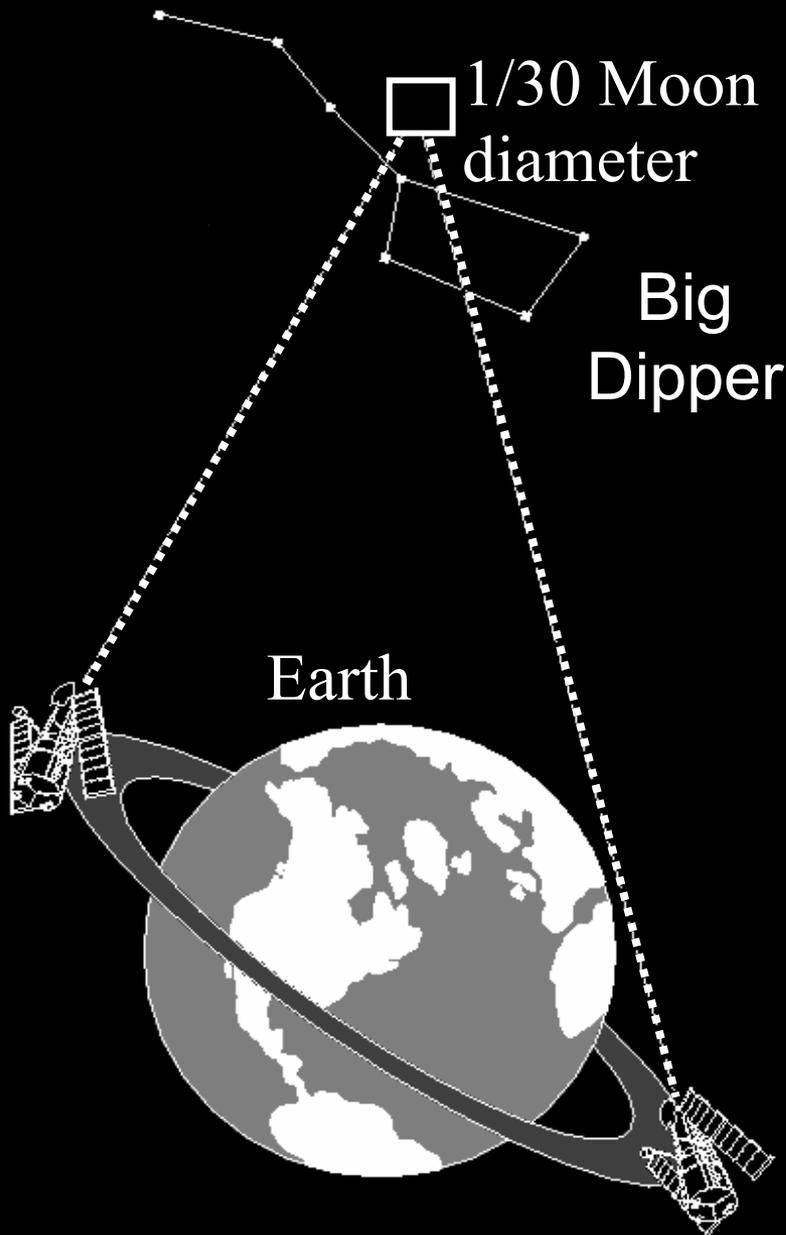


Outer Space - The Cosmos

The
Hubble
Deep
Field



Sun



1/30 Moon
diameter

Big
Dipper

Earth

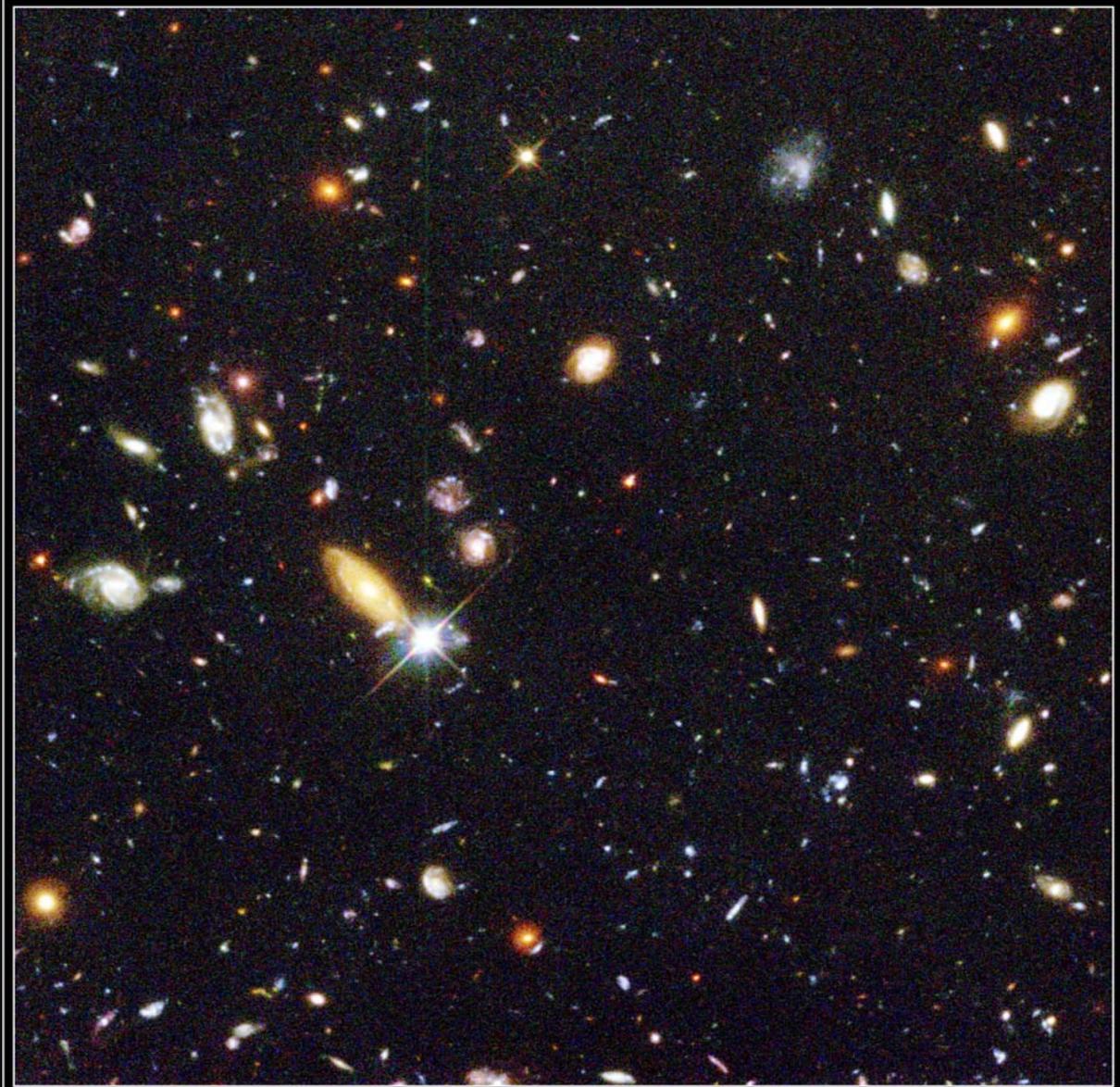
Hubble deep field

**UNIVERSE
OF
GALAXIES**

3000
here



50 billion
over entire
sky



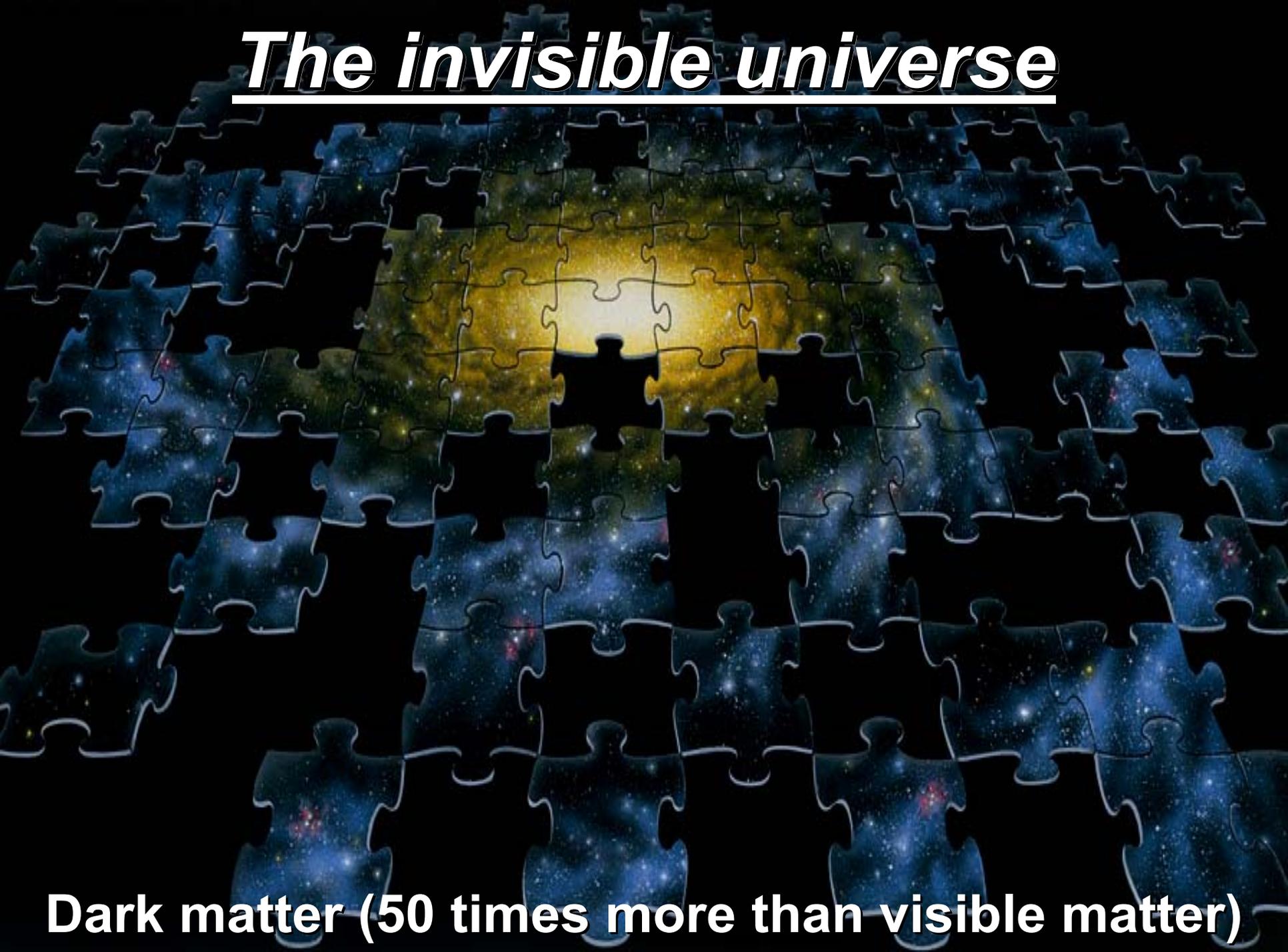
The visible universe



M63

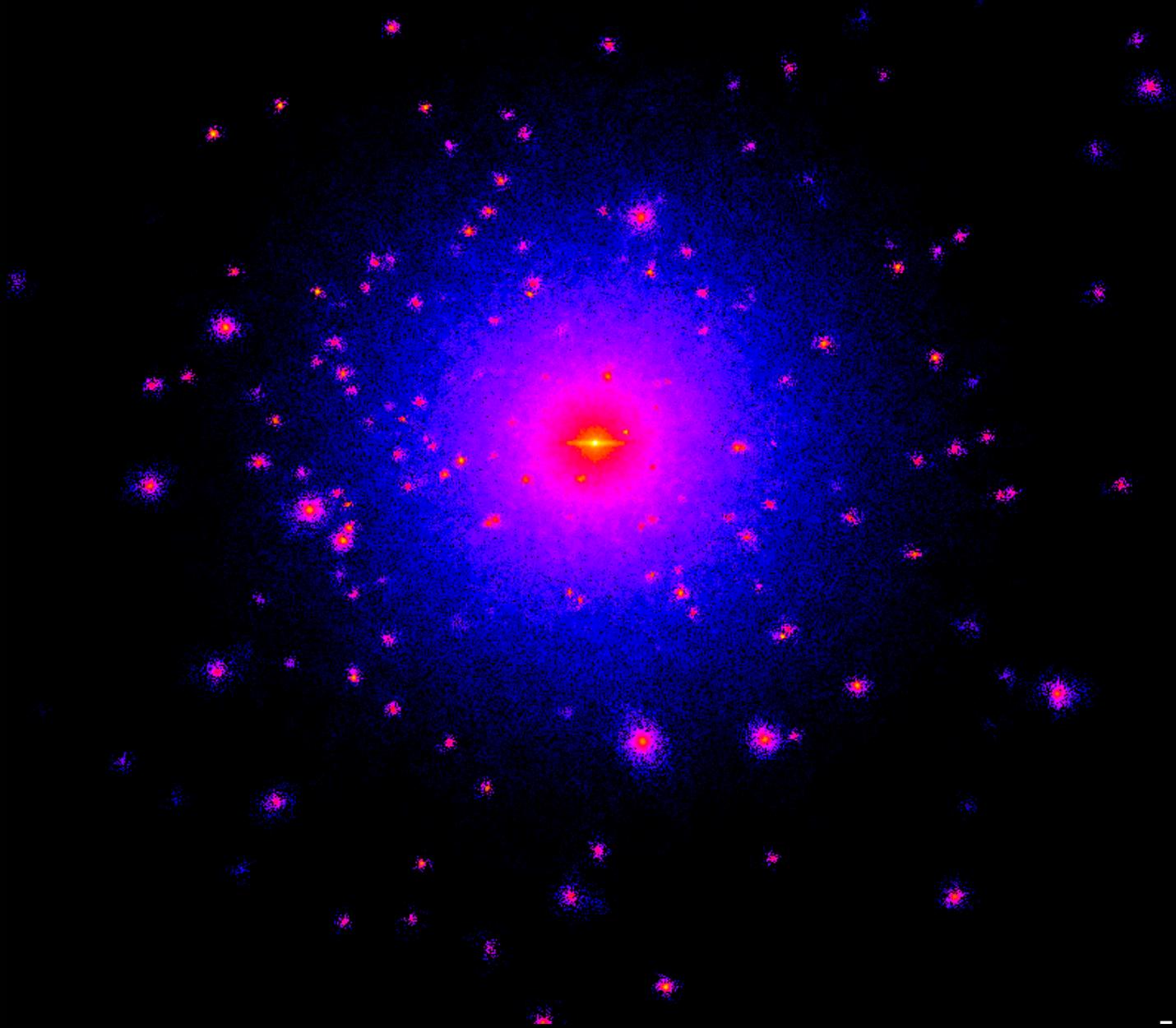
Galaxies

The invisible universe



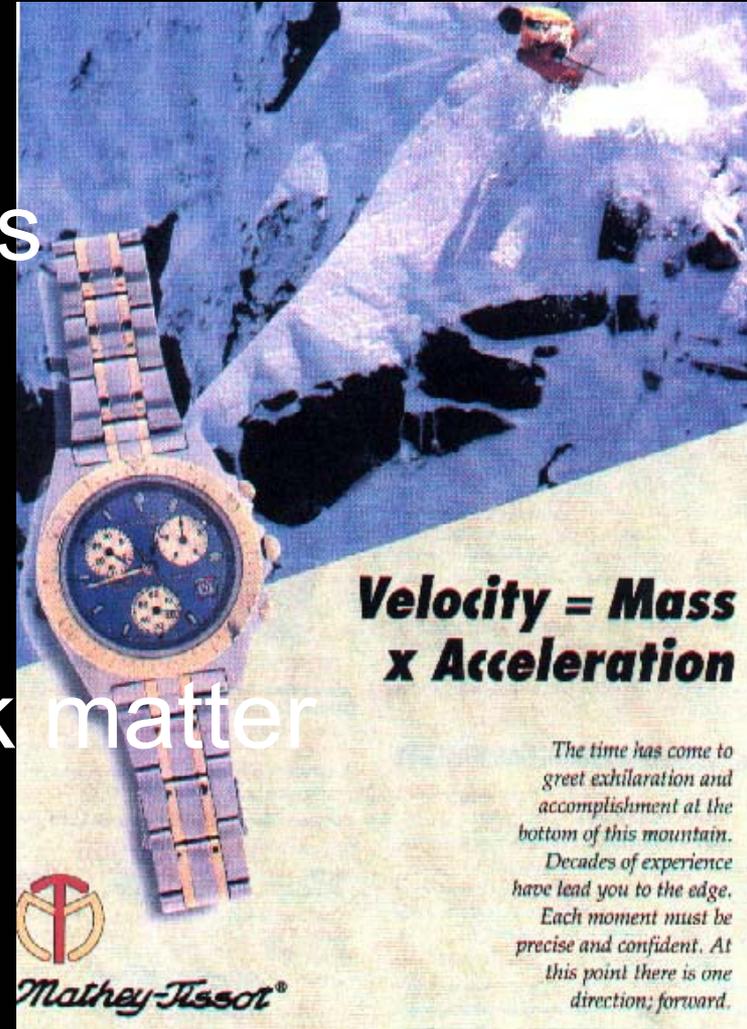
Dark matter (50 times more than visible matter)

If we could “see” dark matter



Dark matter?

- Modified Newtonian dynamics
- Planets
- Mass disadvantaged stars
 - brown
 - red
 - white
- Black holes
- Nonbaryonic particle dark matter



**Velocity = Mass
x Acceleration**

The time has come to greet exhilaration and accomplishment at the bottom of this mountain. Decades of experience have lead you to the edge. Each moment must be precise and confident. At this point there is one direction; forward.


Matherly Tissot®

Dark energy?

Space and time are related.

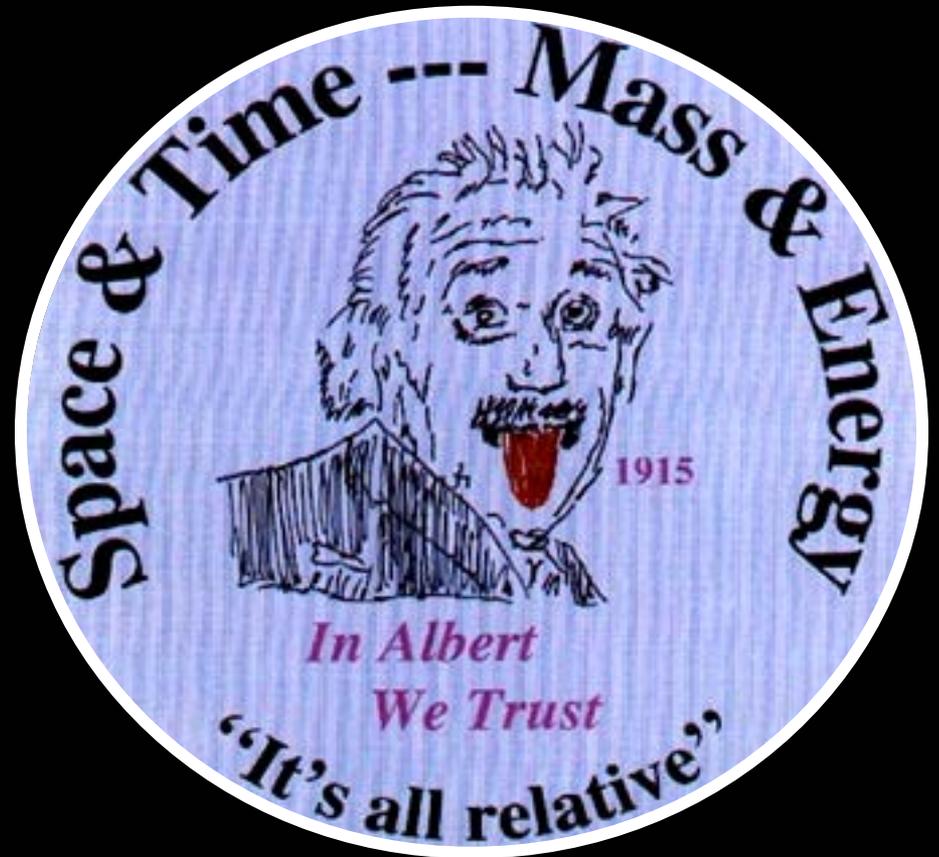
1905

Space is dynamical (curved, warped, bent).

1915

Empty space has a weight.

1917





the weight of space

Cosmological

constant

(dark energy)

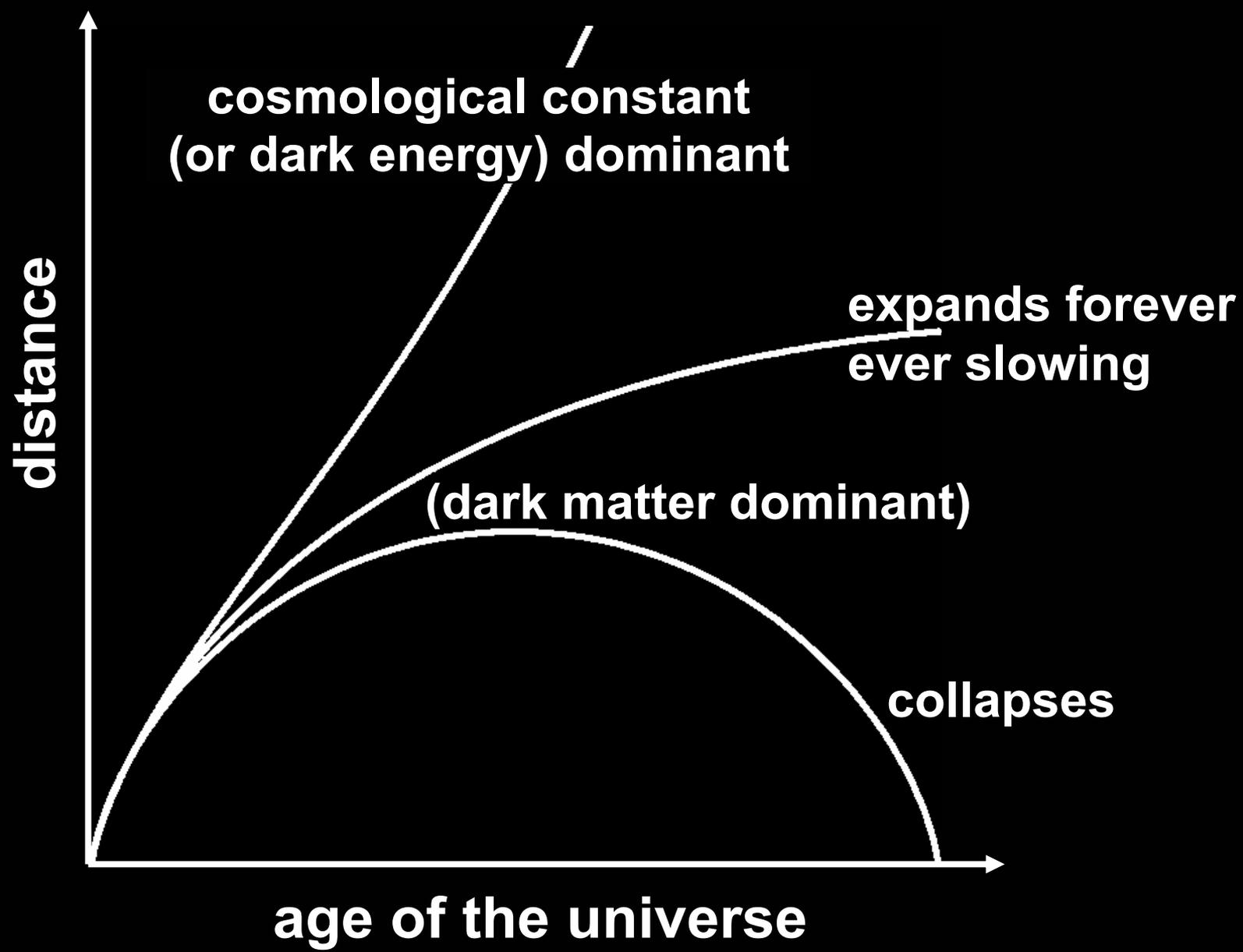
1917 Einstein proposed cosmological constant.

1929 Hubble discovered expansion of the universe.

1934 Einstein called it “my biggest blunder.”

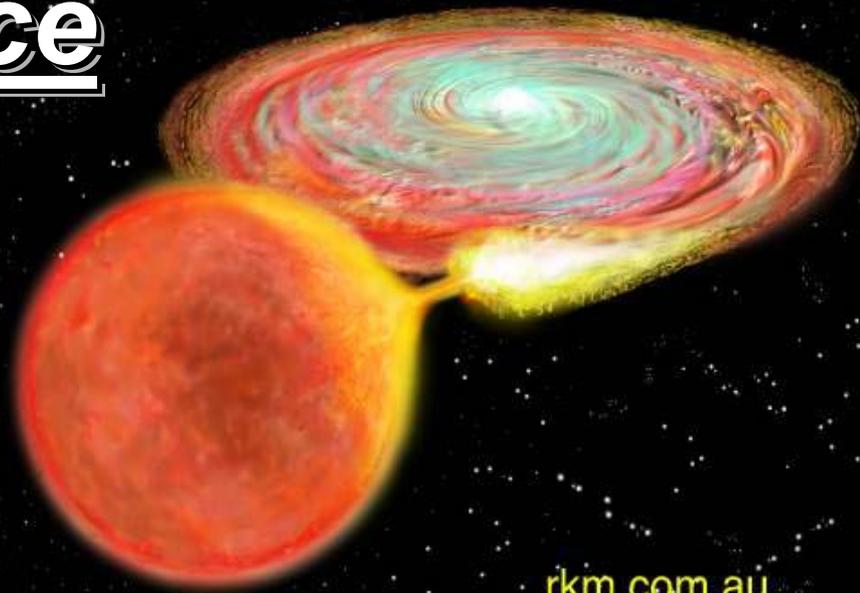
1998 Astronomers found evidence for it.

Cosmological constant (dark energy)



The weight of space

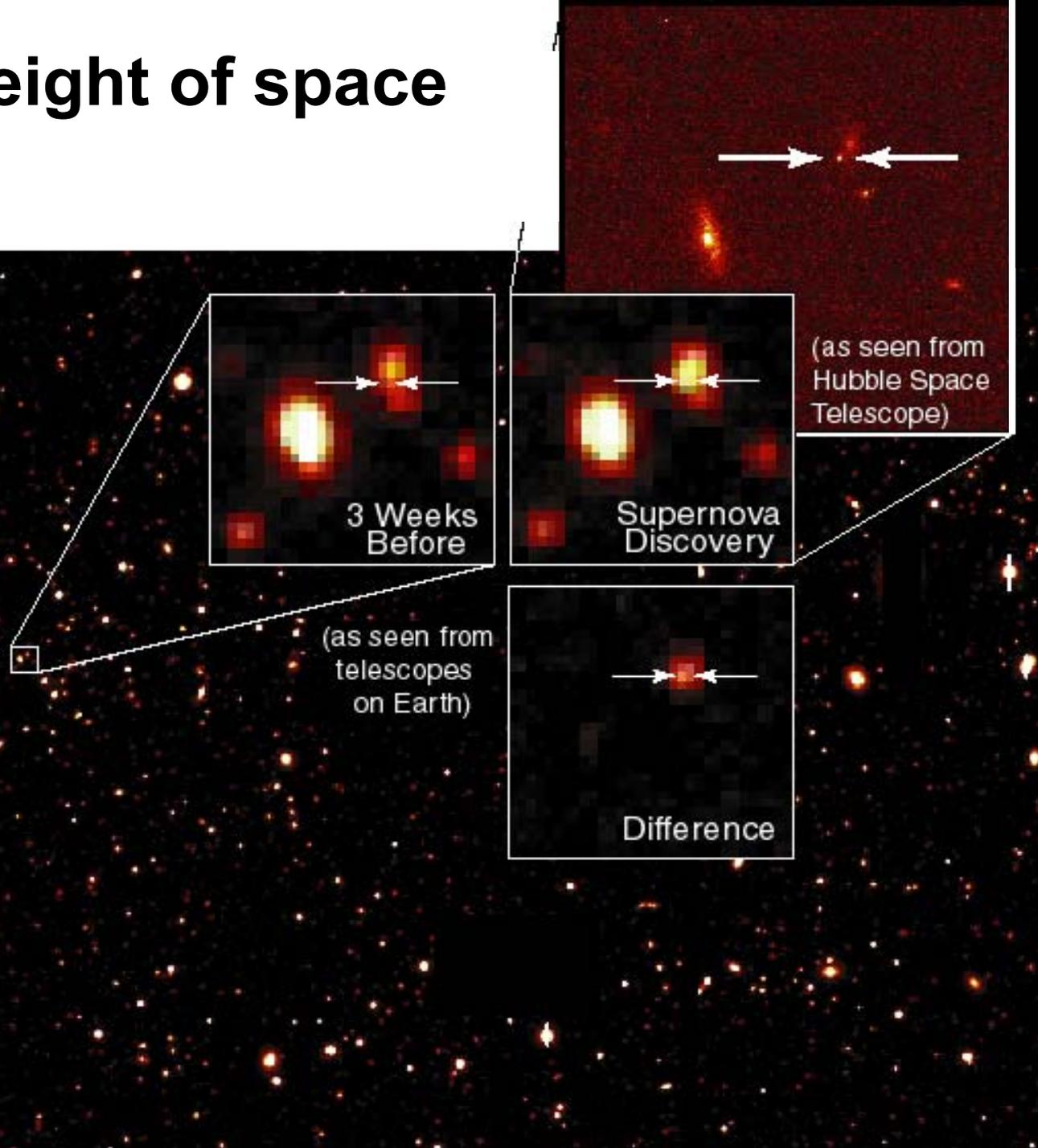
Supernovae



rkm.com.au



The weight of space



Cosmological constant (dark energy)

Mass density of space: $10^{-30} \text{ g cm}^{-3}$

The unbearable lightness of nothing!

Cosmo-illogical constant?

Much ado about nothing
(the vacuum)

NOTHING is something!

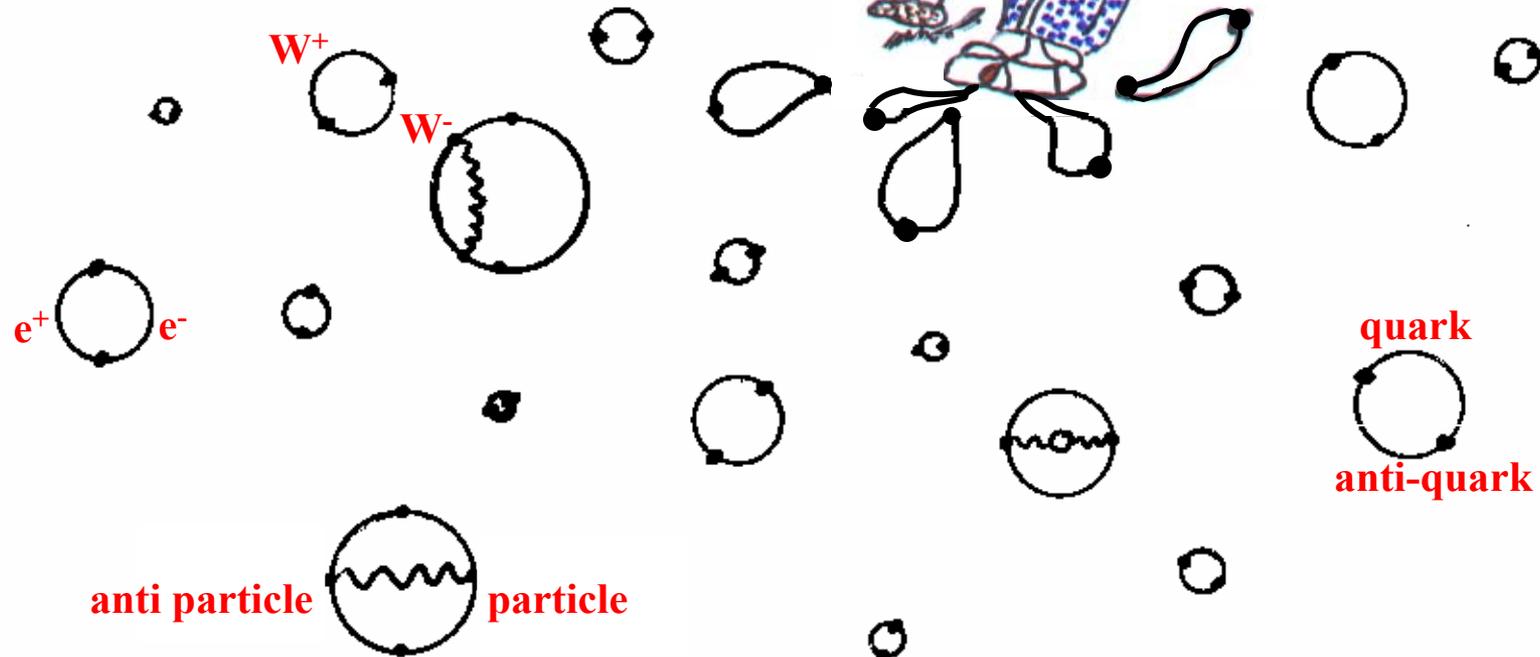
NOTHING has energy!

NOTHING matters!

NOTHING changes!

Quantum Uncertainty

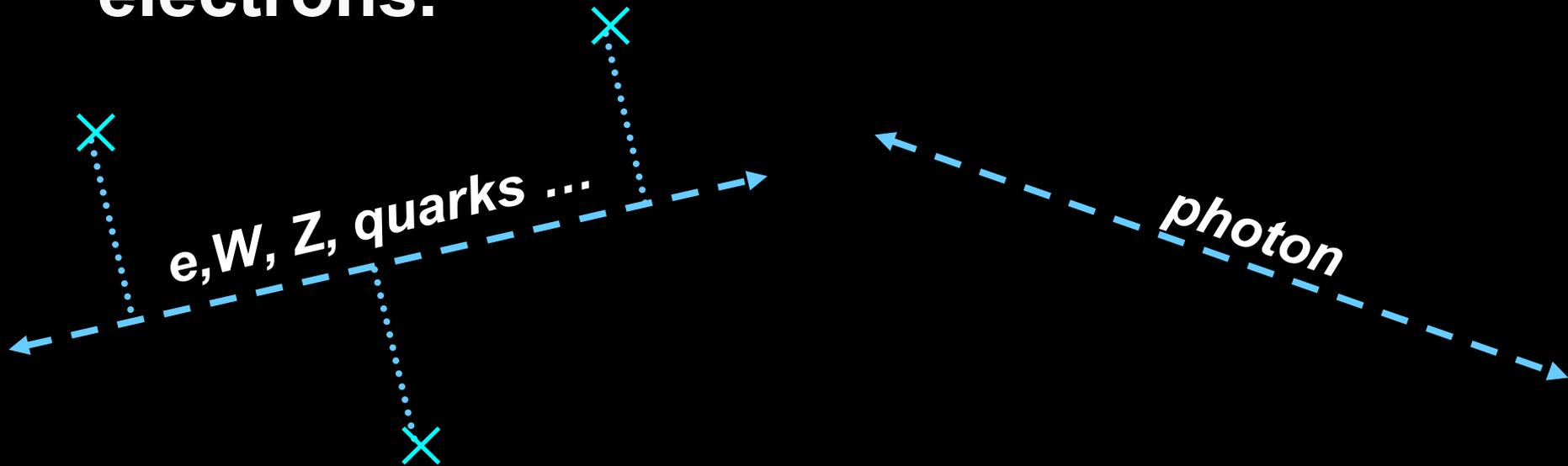
and the Vacuum



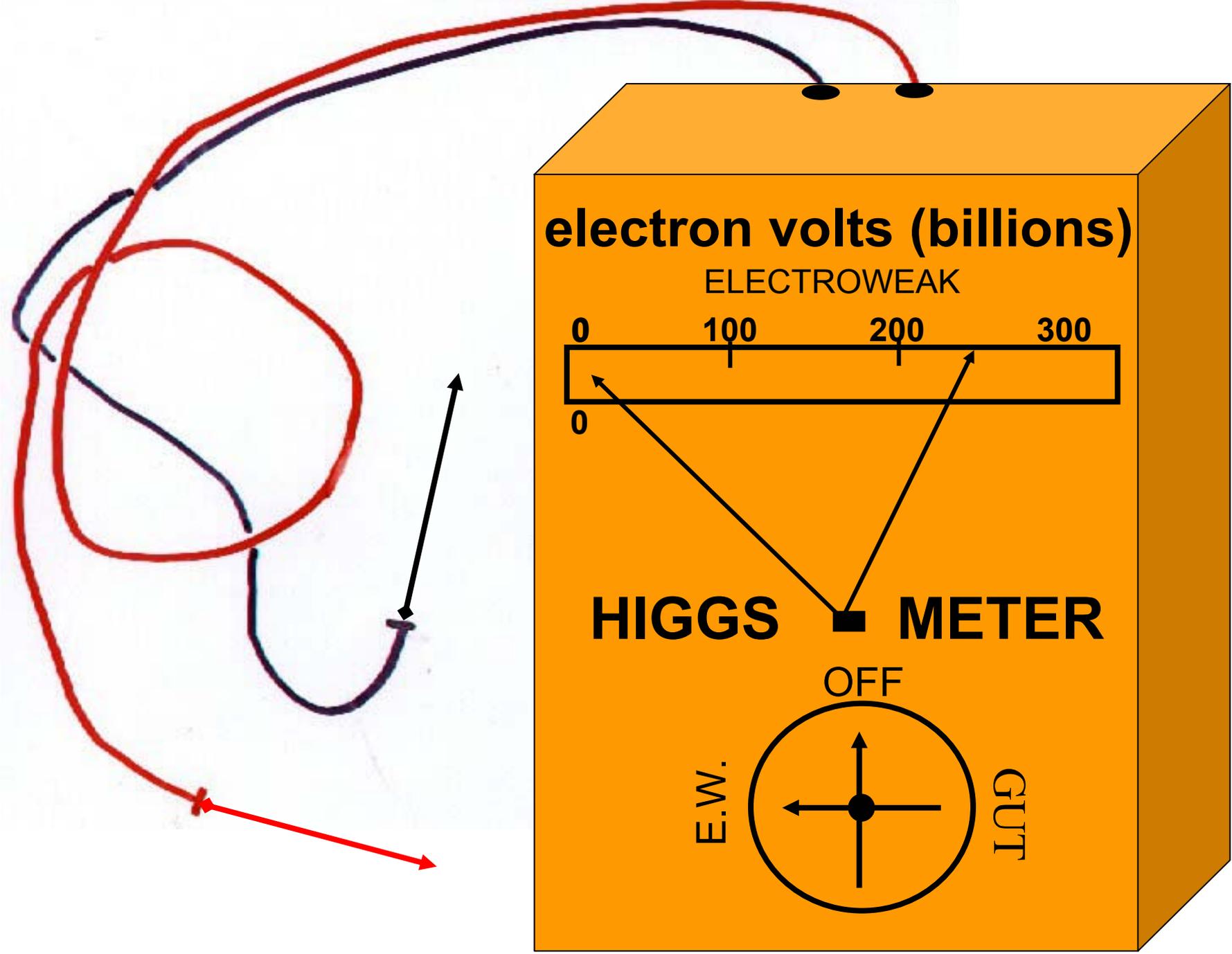
Nothing is something!

The Higgs potential

- The vacuum has a “Higgs potential”
- Interaction with the Higgs field potential gives mass to particles like quarks and electrons.



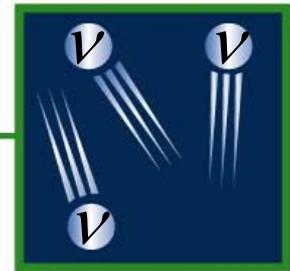
Nothing has energy:



Cosmic Pie



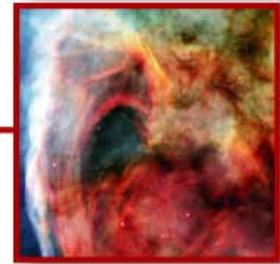
**Chemical Elements:
(other than H & He) 0.03%**



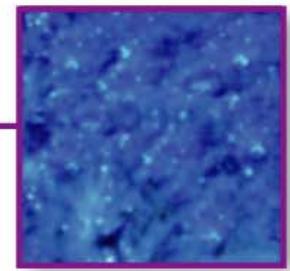
**Neutrinos:
0.47%**



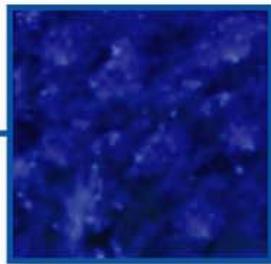
**Stars:
0.5%**



**Free H
& He:
4%**

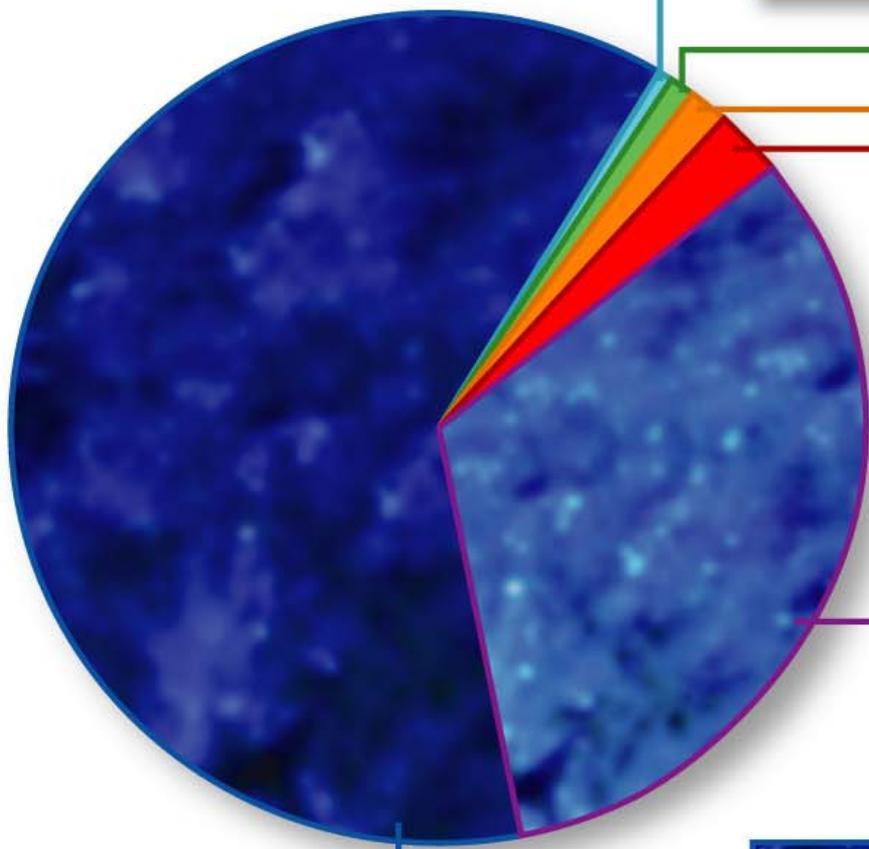


**Dark Matter:
25%**

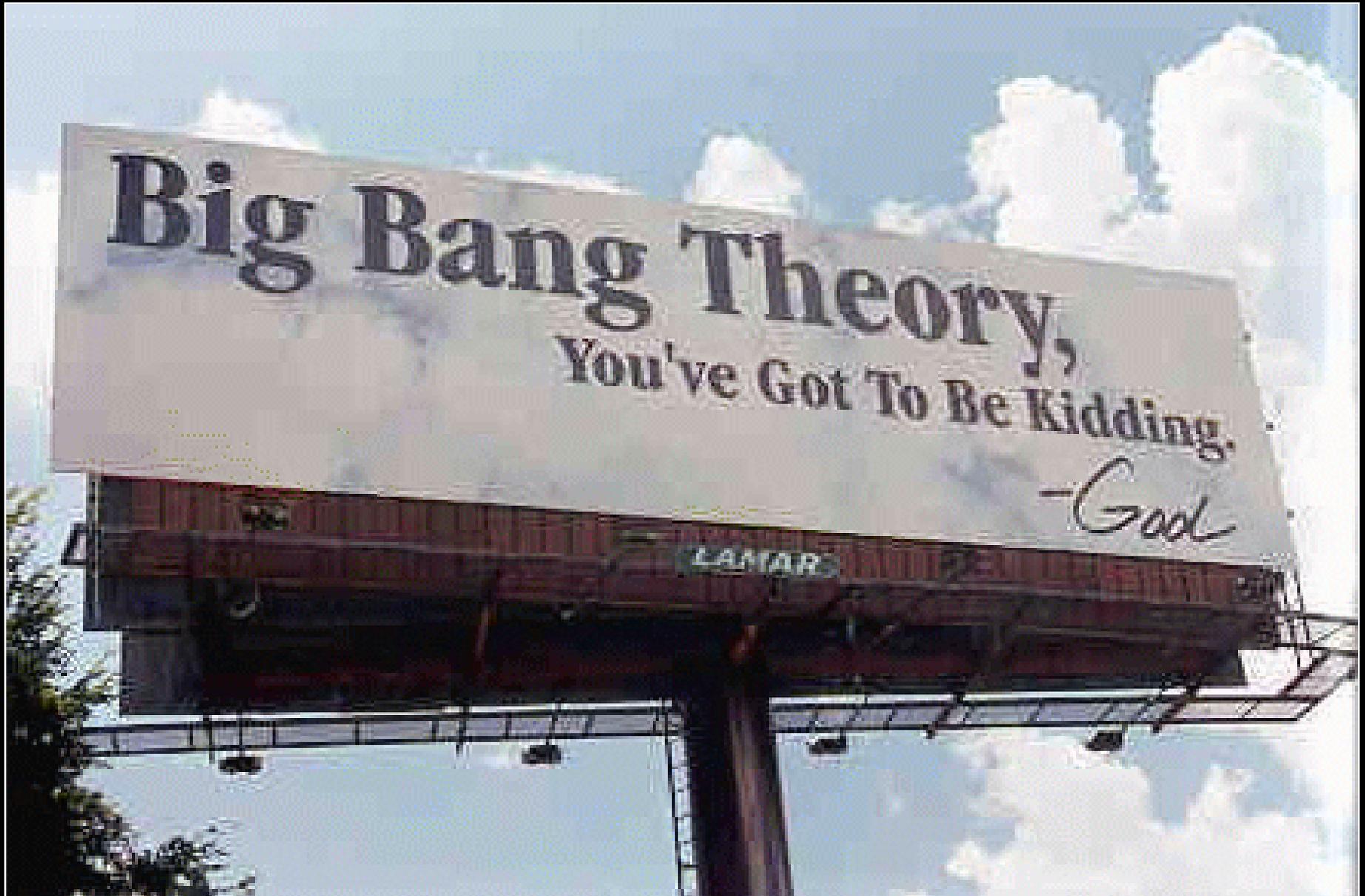


**Dark Energy:
70%**

***Nothing
matters!***



Nothing can change!



Space expands.

Edwin Hubble
1929



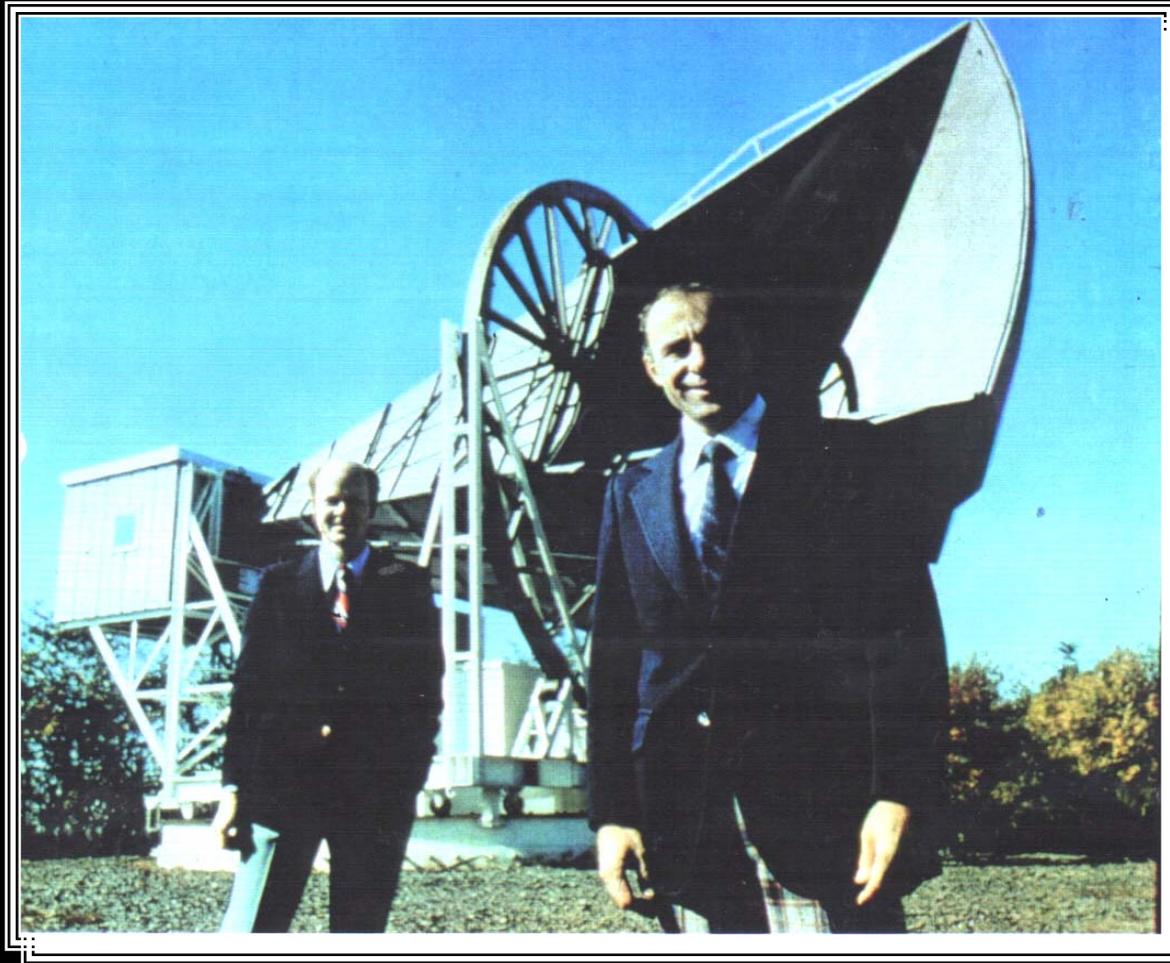
The University of Chicago



1909 National Champions

**The universe
is radiant.**

**Arno Penzias
Robert Wilson
1965**



Cosmic background radiation



$$T = 3K = -454^{\circ} F$$

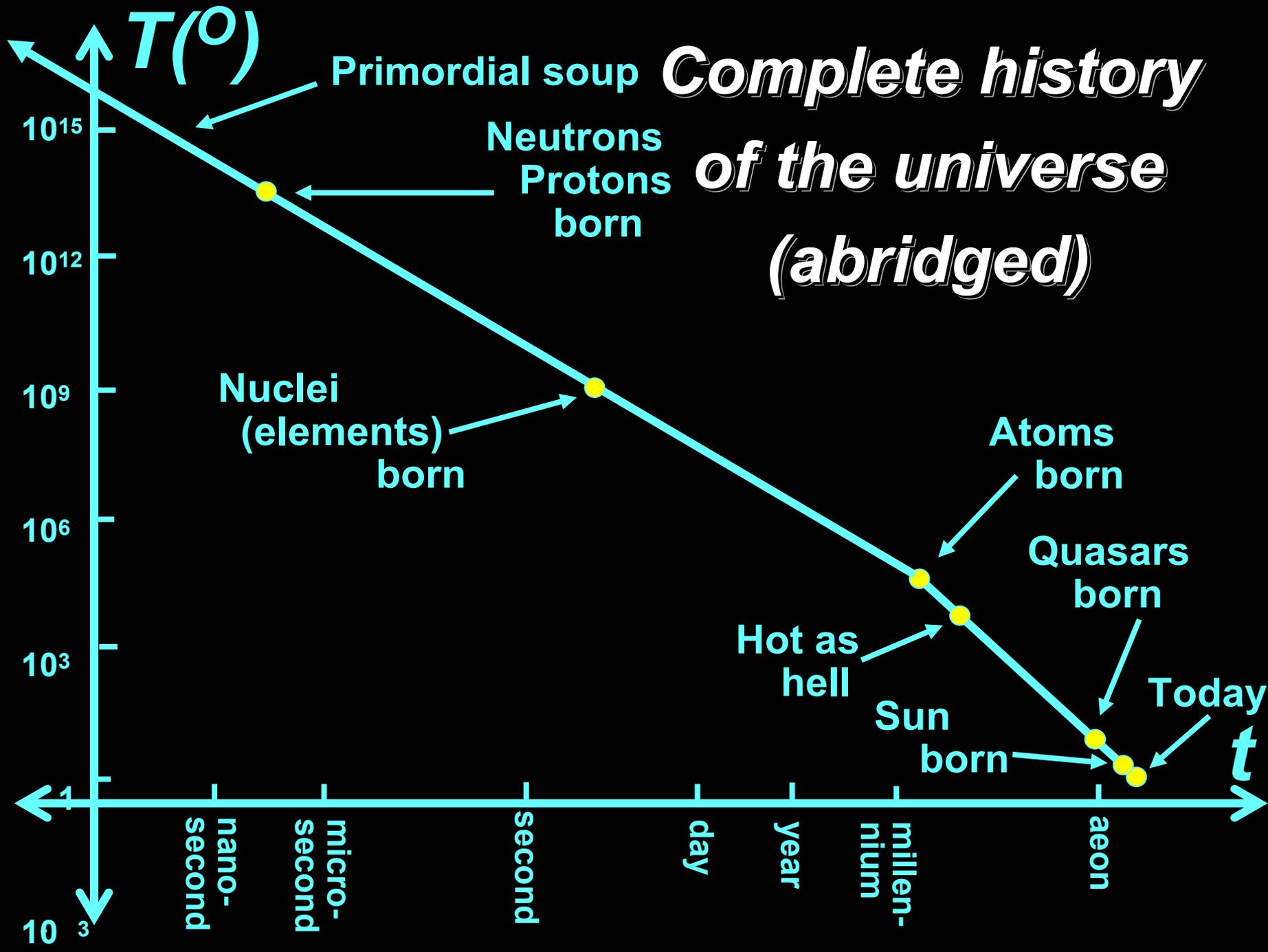
Every cubic inch of space is a

MIRACLE!

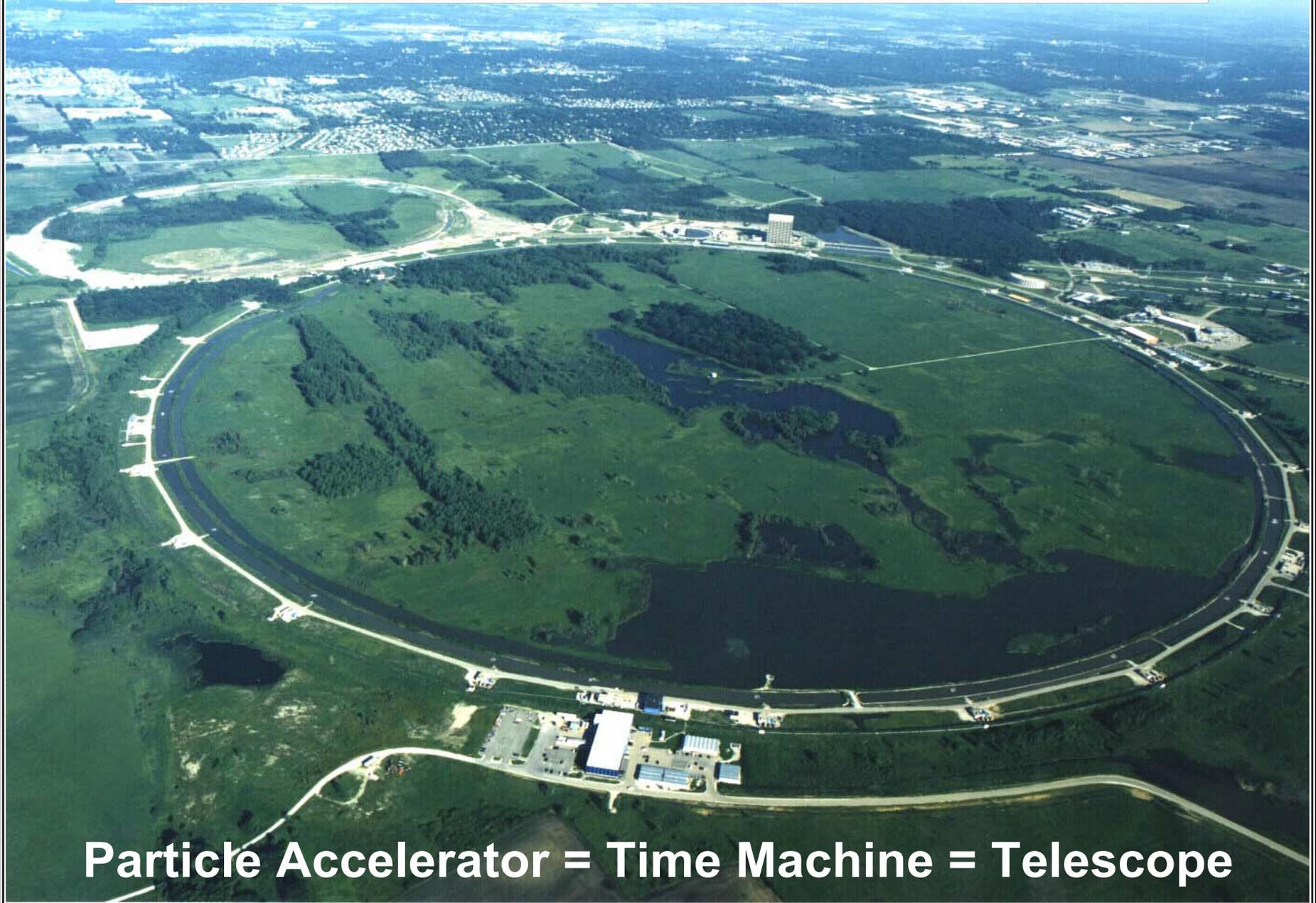
- Walt Whitman

- background radiation
- virtual particles
- Higgs potential
- dark matter
- dark energy

Complete history of the universe (abridged)



Inner Space - The Quantum



Particle Accelerator = Time Machine = Telescope



Fermilab's



Primordial

SOUP

Primordial soup

0.000 000 000 004 seconds AB

3,000,000,000,000,000°

CONDENSED

in } 50 Earth masses in matter
one } 50 Earth masses in antimatter
can } + extra mountain of matter

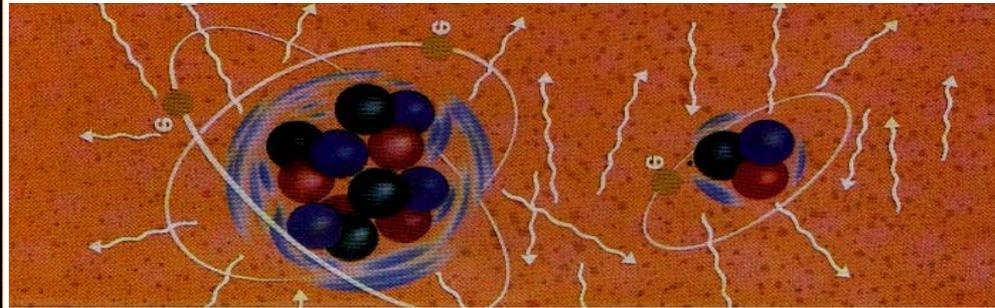
HOT

per } 10 billion years of total
serving } energy output of sun

INGREDIENTS

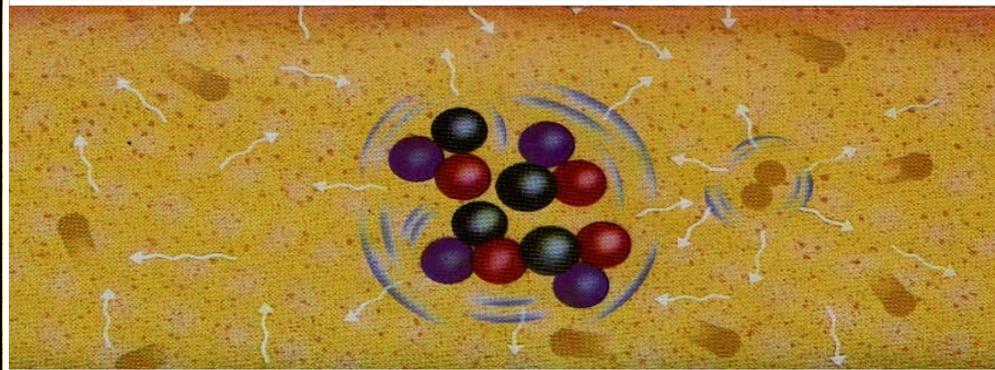
in every spoonful } every type of elementary particle

**300,000
years**



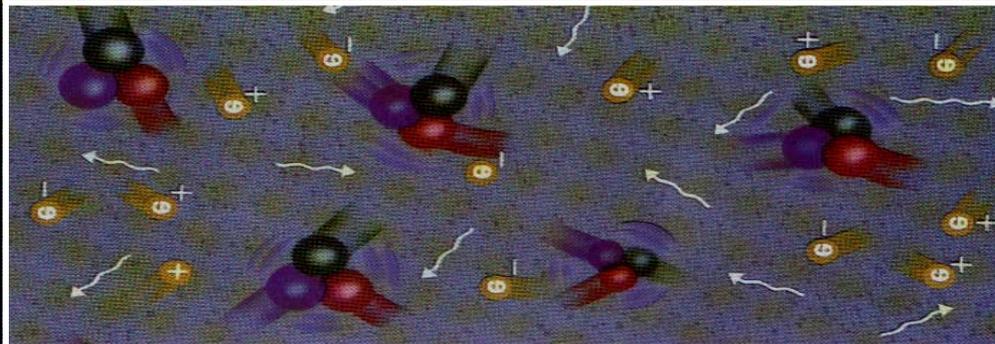
**atoms
form**

**3
minutes**



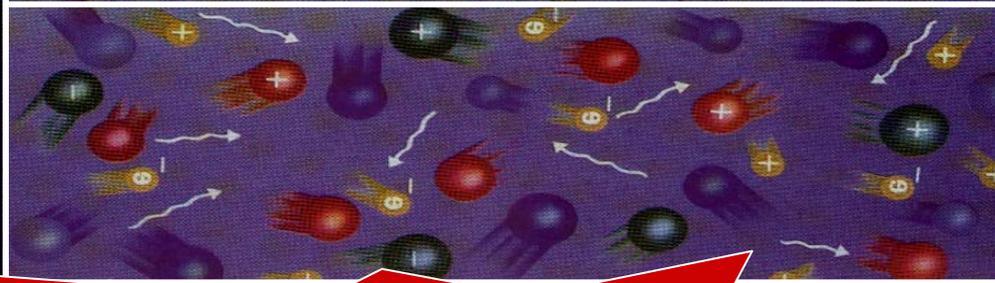
**nuclei
form**

**1-micro
second**



**neutrons
protons
form**

**4-pico
seconds**



**primordial
soup**

BANG!

Periodic table - chemist

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba		Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra		Rf	Db	Sg	Bh	Hs	Mt	Uun	Uuu	Uub						
			La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
			Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

Periodic table - cosmologist

H

He

Metals

The Universe Today:

73% Hydrogen (10^{-5} deuterium)
26% Helium (10^{-5} ^3He)
1% Metals

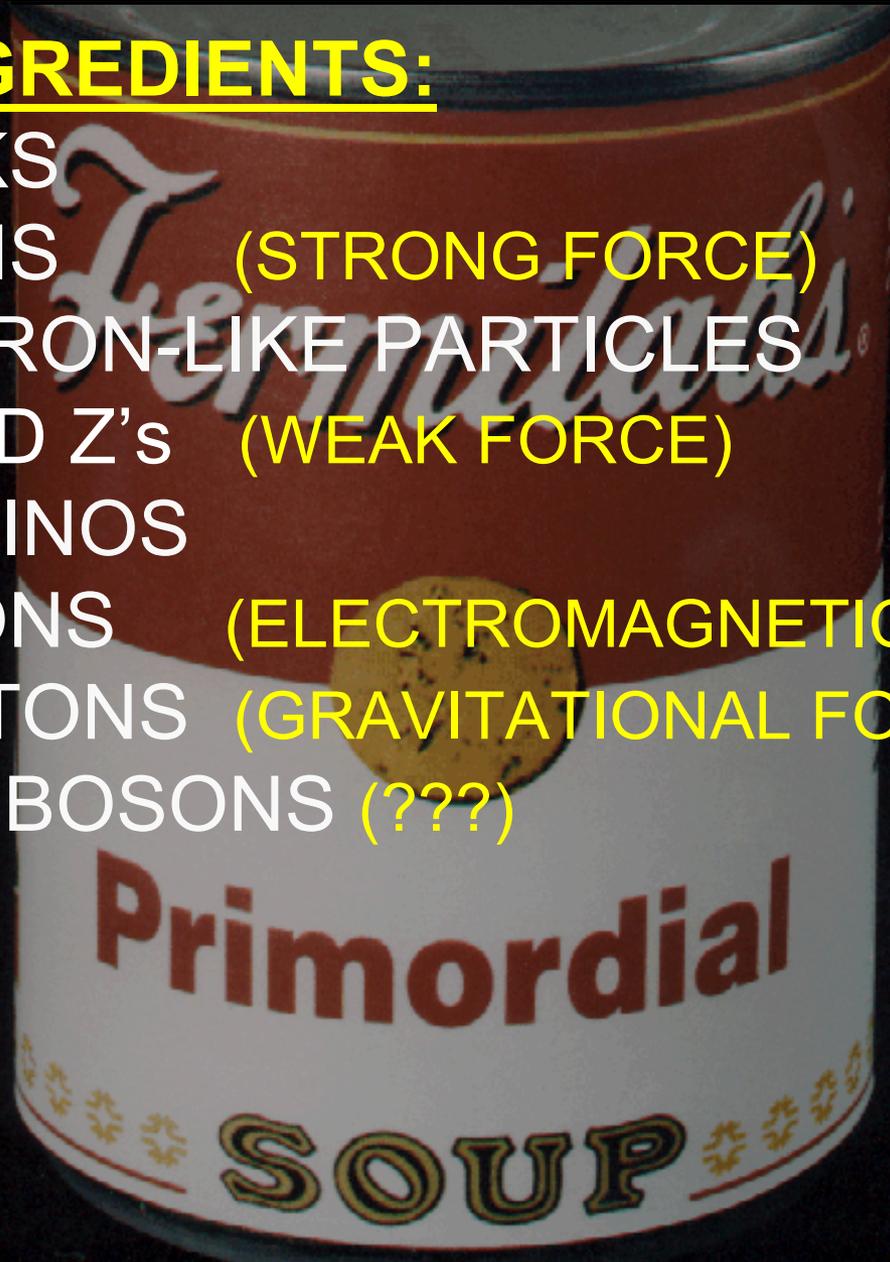
The Universe 3 minutes AB:

76% Hydrogen (10^{-5} deuterium)
24% Helium (10^{-5} ^3He)
 $10^{-8}\%$ Lithium

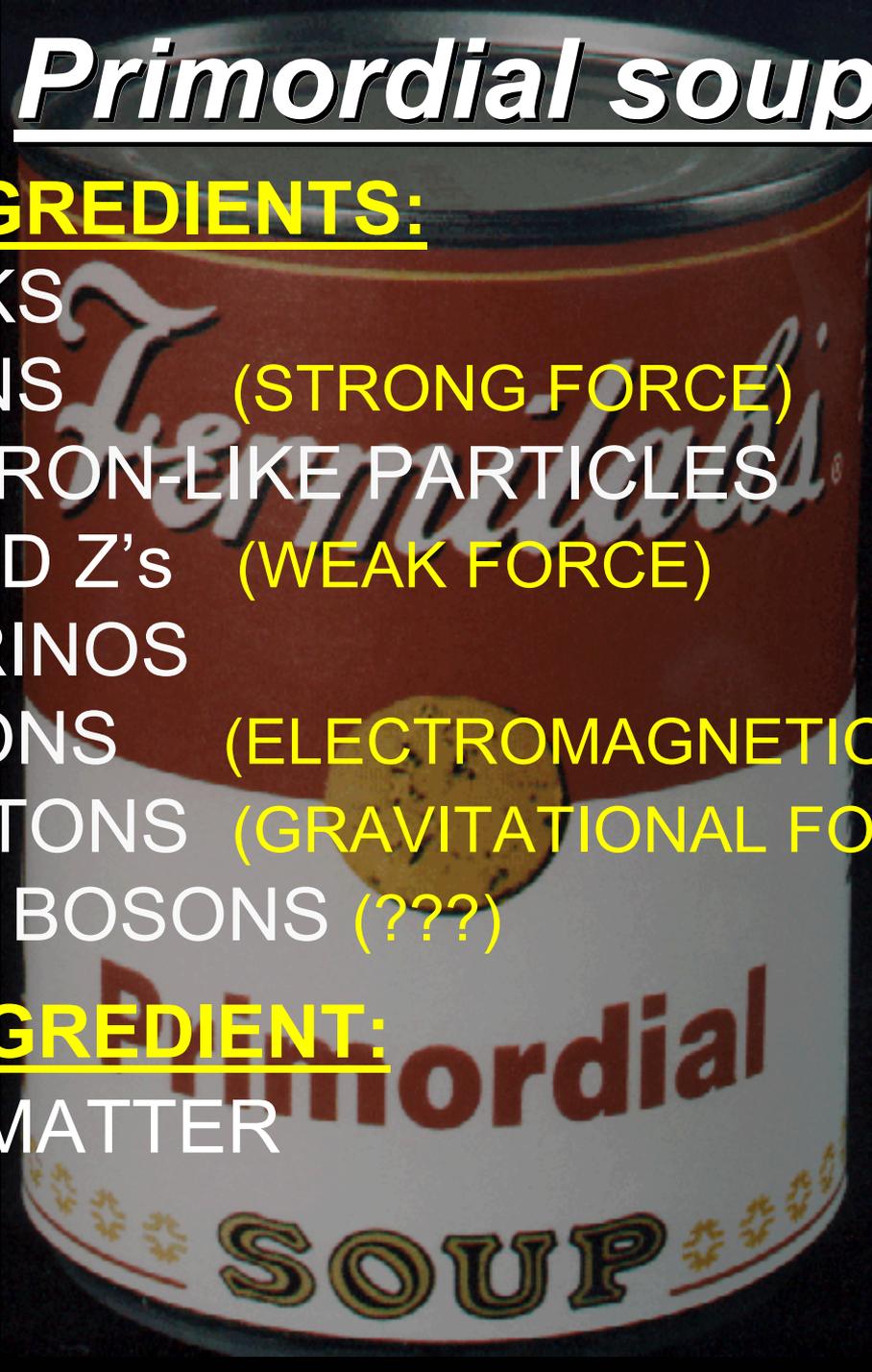
Primordial soup

KNOWN INGREDIENTS:

- 56% QUARKS
- 16% GLUONS (STRONG FORCE)
- 9% ELECTRON-LIKE PARTICLES
- 9% W's AND Z's (WEAK FORCE)
- 5% NEUTRINOS
- 2% PHOTONS (ELECTROMAGNETIC FORCE)
- 2% GRAVITONS (GRAVITATIONAL FORCE)
- 1% HIGGS BOSONS (???)



Primordial soup

A can of 'Fermilab's Primordial Soup' is the background for the slide. The can is red and white with a gold seal. The text 'Fermilab's' is written in a cursive font on the red part, and 'Primordial SOUP' is written in a bold, sans-serif font on the white part. The word 'SOUP' is particularly large and stylized. The ingredients list is overlaid on the left side of the can.

KNOWN INGREDIENTS:

56% QUARKS

16% GLUONS (STRONG FORCE)

9% ELECTRON-LIKE PARTICLES

9% W's AND Z's (WEAK FORCE)

5% NEUTRINOS

2% PHOTONS (ELECTROMAGNETIC FORCE)

2% GRAVITONS (GRAVITATIONAL FORCE)

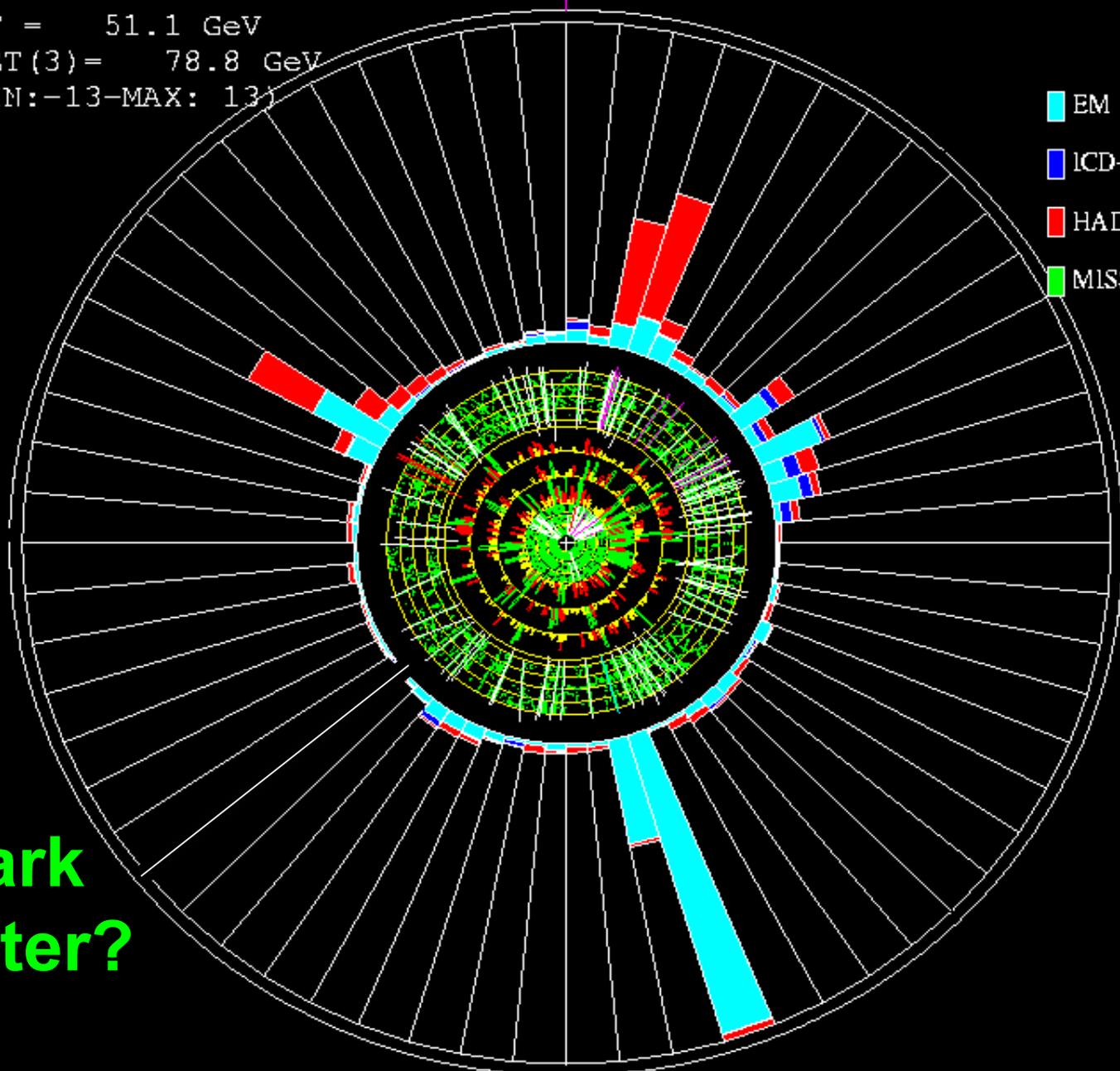
1% HIGGS BOSONS (???)

SECRET INGREDIENT:

DARK MATTER

Max ET = 51.1 GeV
MISS ET(3) = 78.8 GeV
ETA(MIN:-13-MAX: 13)

EM
ICD+MG
HAD
MISS ET



Dark
Matter?

_ MUON
_ ELEC
_ TAUS
_ VEES
_ OTHER

the Neutrinos



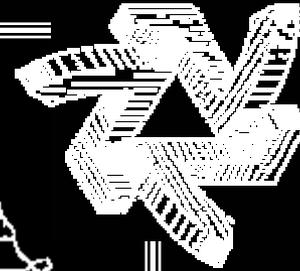
Ballard Firehouse

January 26

February 9

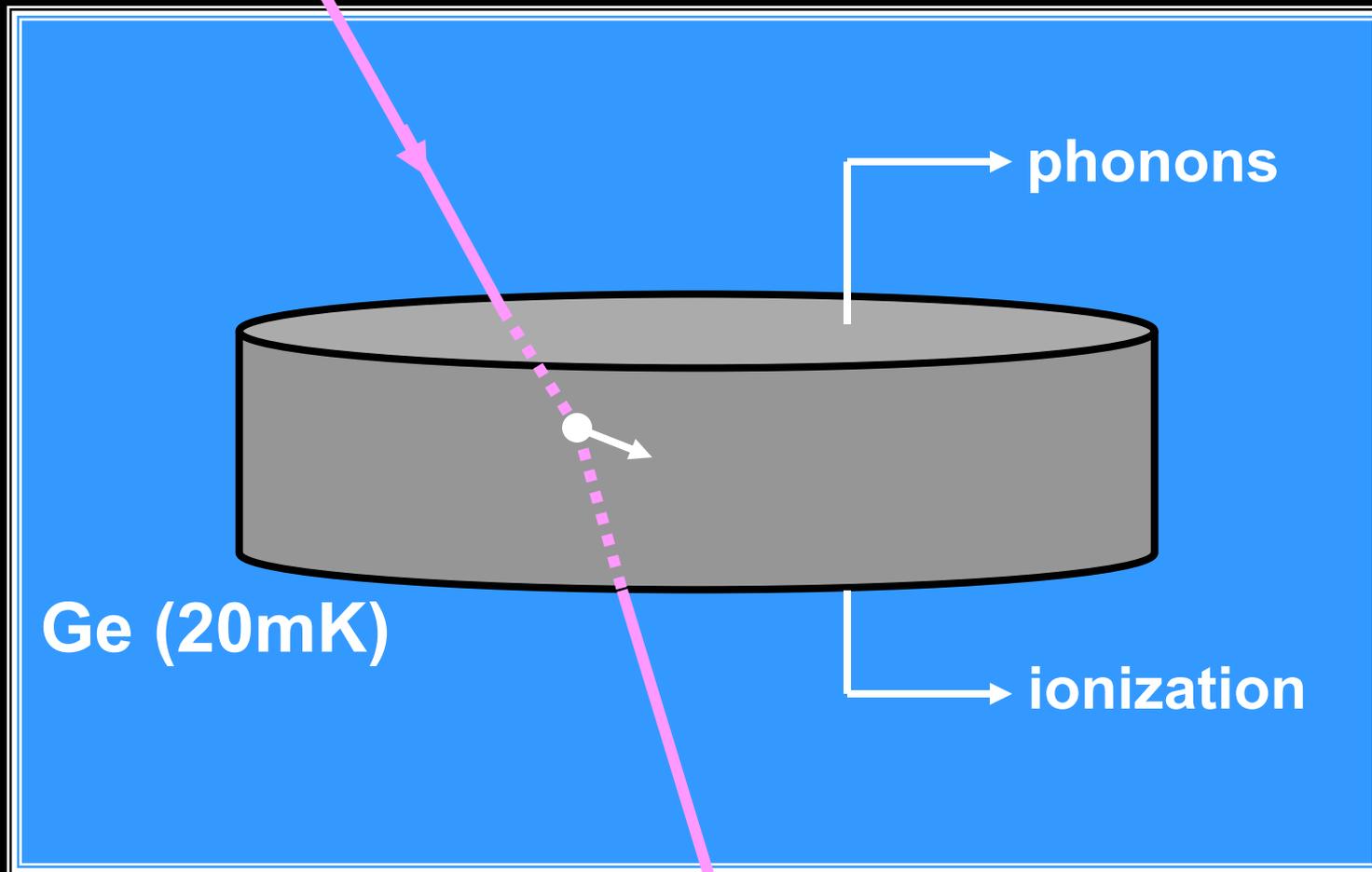
\$3.00

MINOS



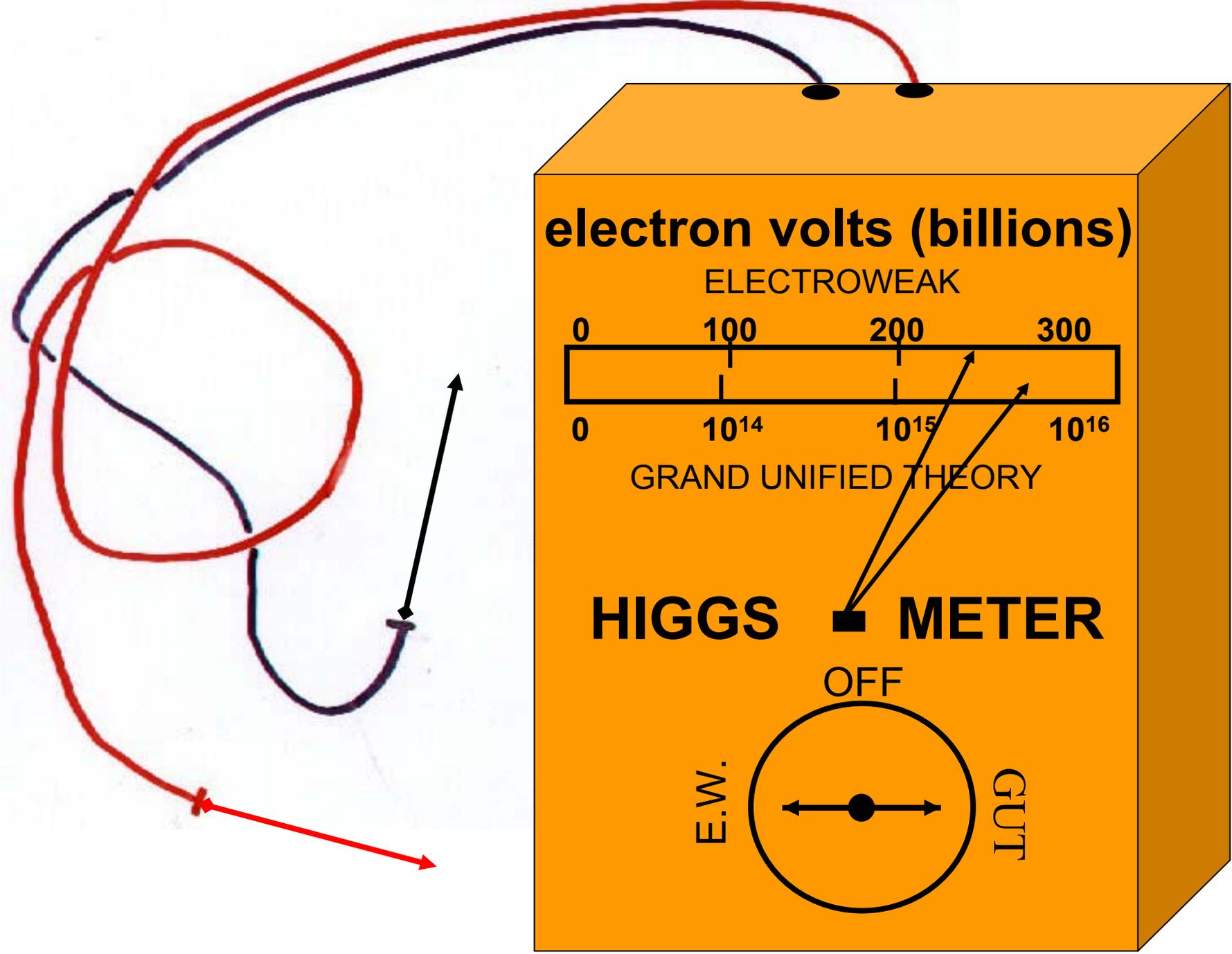
also CERN → Gran Sasso

WIMP (300 km s^{-1})



Before primordial soup?

Nothing!



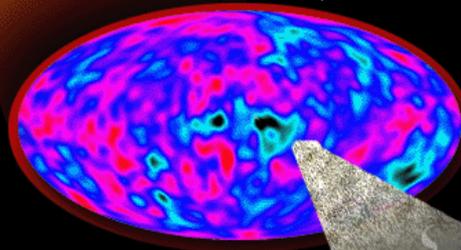
Imprint of Inflation

BIG BANG

Inflation
Big Bang plus
 10^{-32} seconds

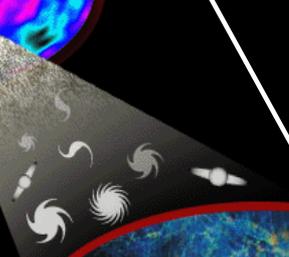
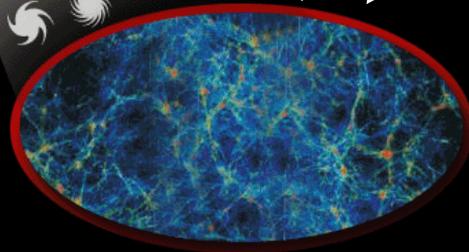


Big Bang plus
380,000 Years



Seeds of Structure
+
Gravitational Waves

Big Bang plus
14 Billion Years



An early particle cosmologist



Erwin Schrödinger

1938-1939: Graz → Vatican → Gent, Belgium → Dublin

The proper vibrations of the expanding universe

Erwin Schrödinger (1939)

Introduction:

production of matter, merely by expansion [of the universe],... Alarmed by these prospects, I have examined the matter in more detail.”

Conclusion:

“... There will be a mutual adulteration of [particles] in the course of time, giving rise to ... the ‘alarming phenomenon’...”

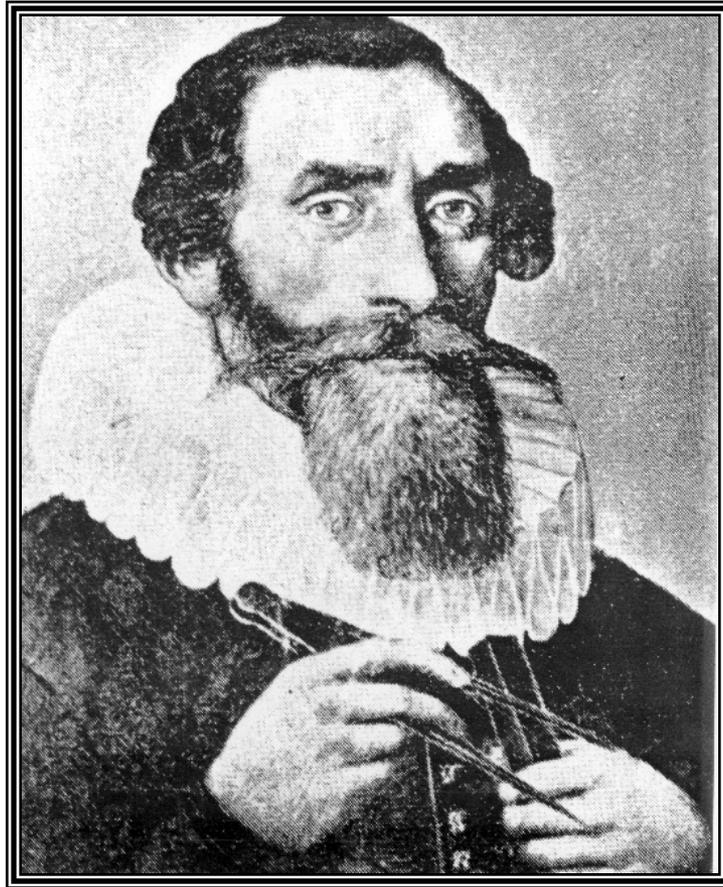
The proper vibrations of the expanding universe

Erwin Schrödinger (1939)

**Creation of a single pair of particles
of undetectably small energy
somewhere in the universe
in the next 14 billion years**

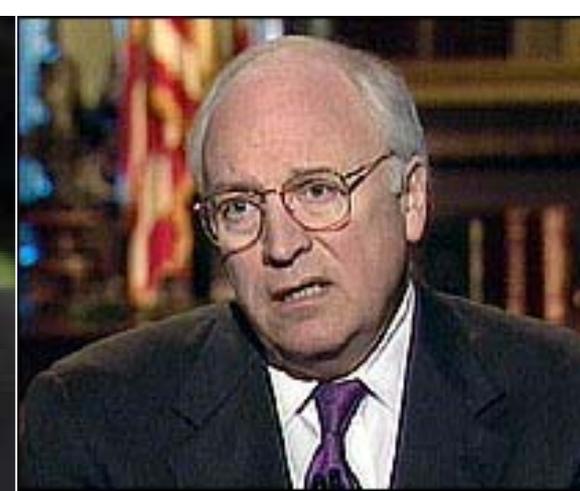
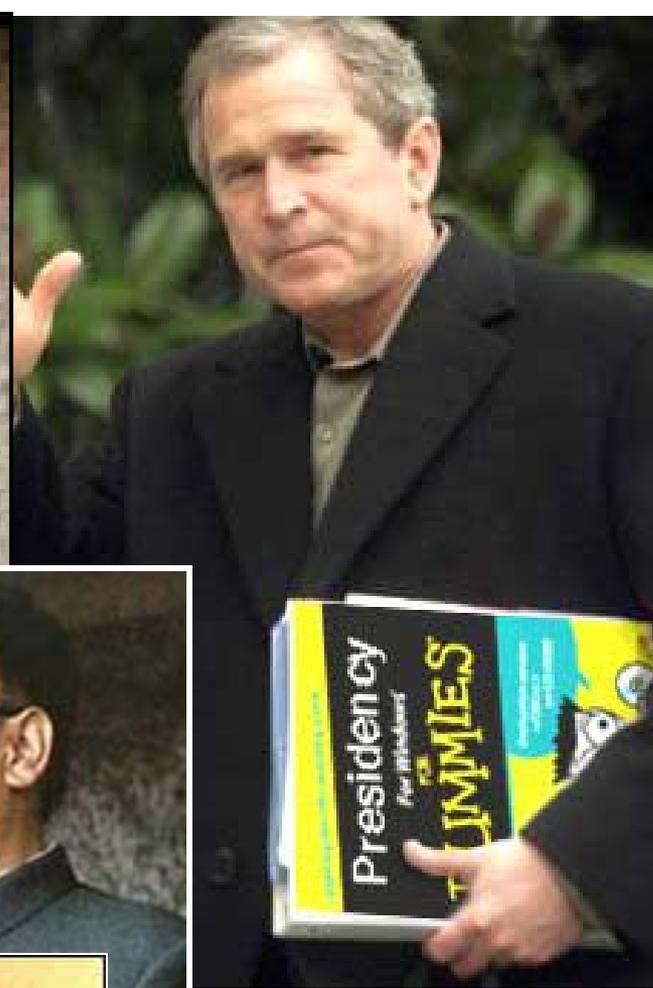
Alarming?

An even earlier Graz cosmologist



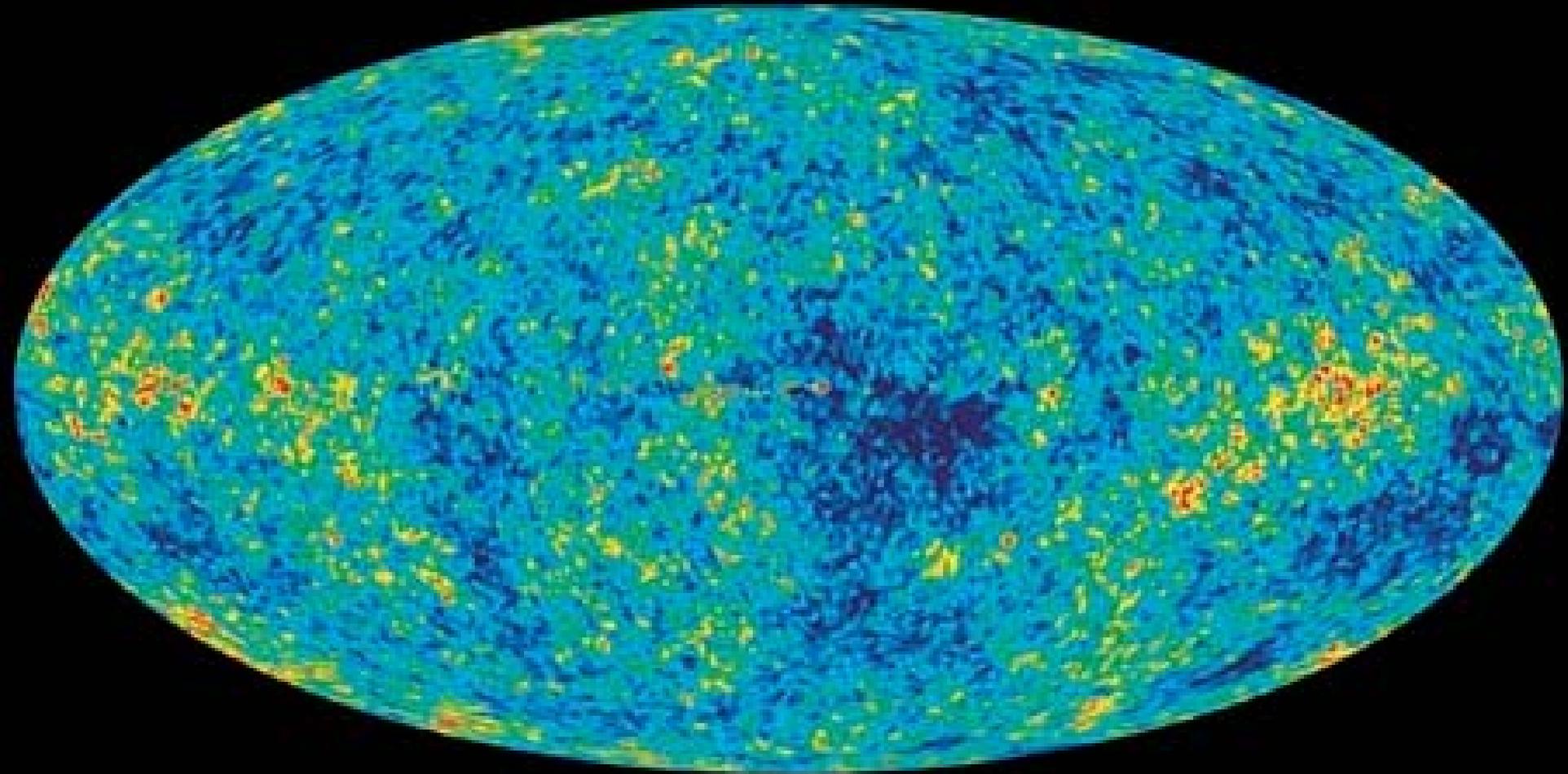
“When the storms rage around us, and the state is threatened by shipwreck, we can do nothing more noble than to lower the anchor of our peaceful studies in the ground of eternity.” - *J. Kepler*

1600-1630: Graz → Prague → Linz → Sagan → Ratisbon



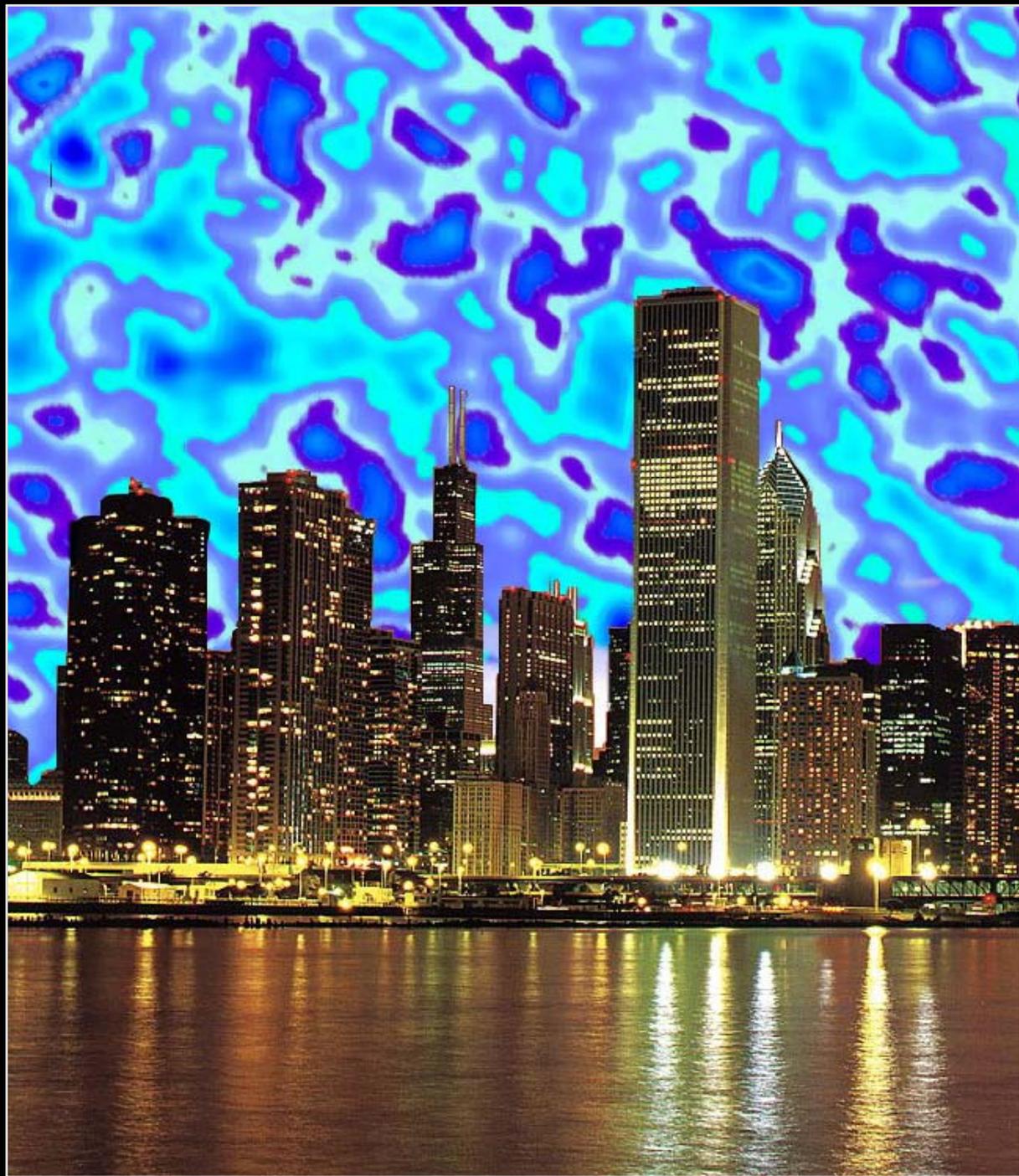
“When the storms rage around us, and the state is threatened by shipwreck, we can do nothing more noble than to lower the anchor of our peaceful studies . . .

Quantum uncertainty—inner space



Temperature ripples—outer space

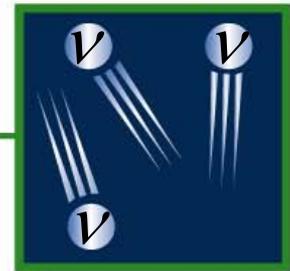
**A pattern
of
vacuum
quantum
fluctuations
(the alarming
phenomenon)**



Cosmic Pie



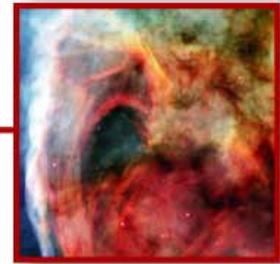
**Chemical Elements:
(other than H & He) 0.03%**



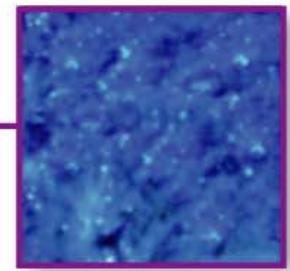
**Neutrinos:
0.47%**



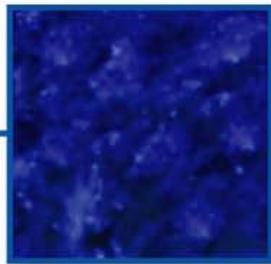
**Stars:
0.5%**



**Free H
& He:
4%**

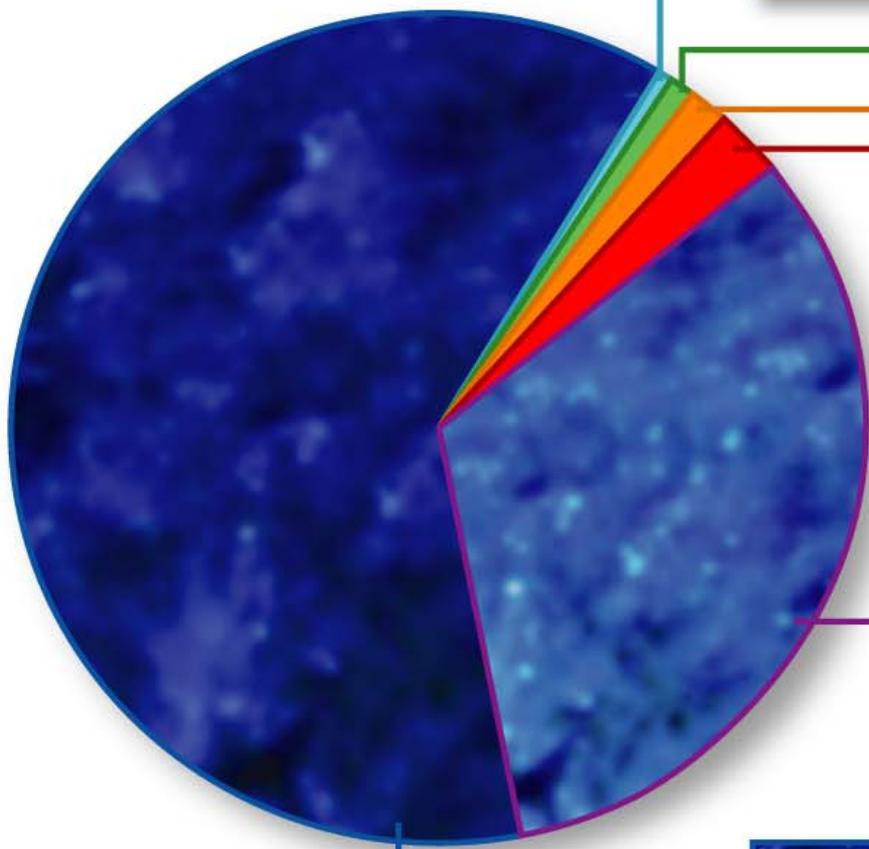


**Dark Matter:
25%**



**Dark Energy:
70%**

**95%
*mystery***



DECEMBER 31, 1999 \$4.95

www.time.com

PERSON OF THE CENTURY

TIME

ALBERT
EINSTEIN

DECEMBER 31, 2000 \$4.95

www.time.com

PERSON OF THE NEXT CENTURY

TIME

?

The big bang



http://home.fnal.gov/~rocky/summer_03.pdf

Rocky Kolb
Fermilab and the
University of Chicago